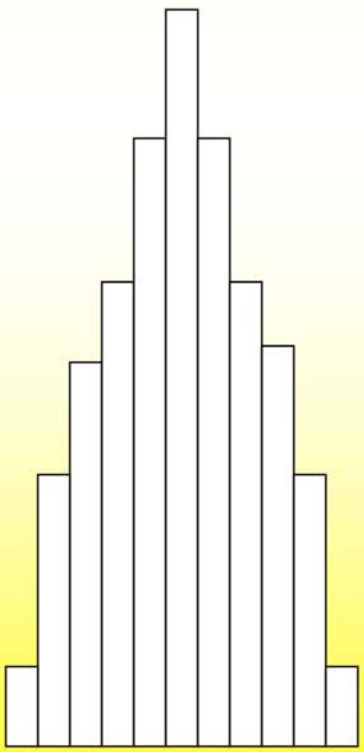
Event Simulation using Monte Carlo Methods



Renee Harton
Massachusetts Institute of Technology
SULI Program

Supervisor: Dr. Stephen Mrenna
Computing Division
Fermi National Accelerator Laboratory
Batavia, Illinois

Reasons to use simulations

- Each experiment requires extreme precision, sometimes less than 1% error.
- This required precision results in experiments that are often costly.
- Every experiment is simulated before it is actually run.
- Simulations of the particle collisions that need to be analyzed are detected using simulations of the detector.
- These simulations allow the lab scientists to:
  - better understand their instruments.
  - calibrate and understand the readings of the equipment.

My Objective

- To simulate the collision of particles, using Pythia, an event generator, and Monte Carlo Methods.

First Simulated Collision

To simulate an electron and positron collision

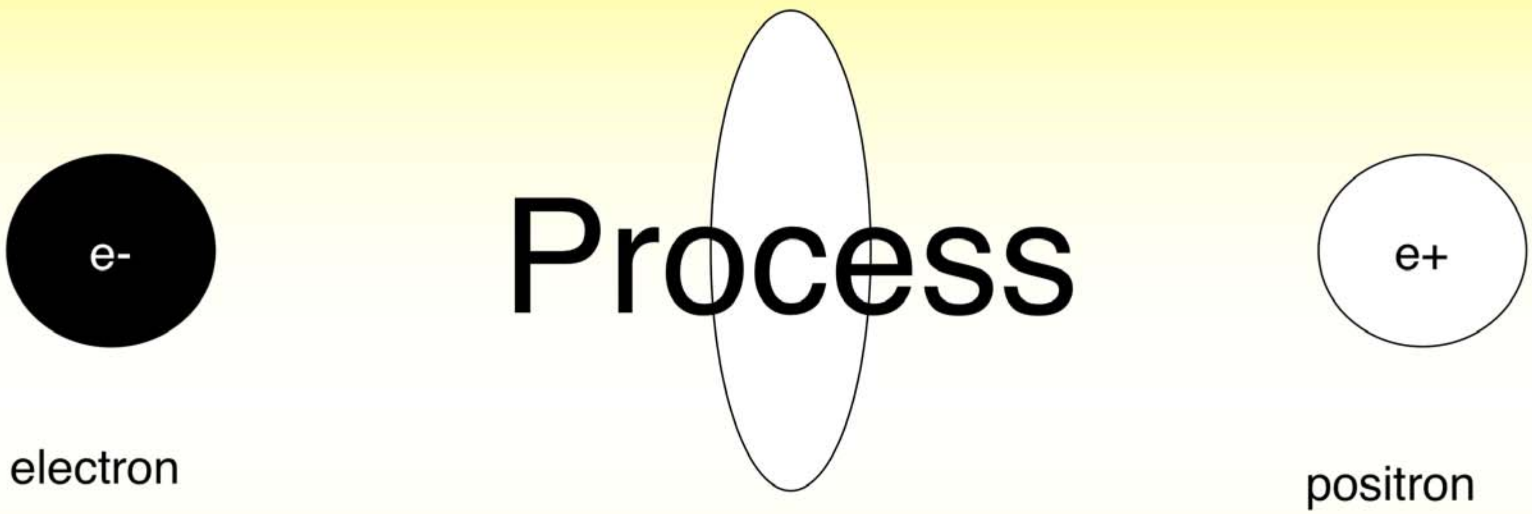
Example of an hbook file

Input file, with explanations:

zboson	Name of log and histogram file. Change when you want to save results.
MSEL=0	Pick the process by hand.
MSUB(1)=1	Pick Z-boson production
MSTP(11)=0	Behavior of e - beam (0=electron carries all the energy)
MSTP(43)=1	Composition of "Z" boson: 1= just photon, 2=just Z, 3=full interference
MSTP(61)=0	Initial state radiation (0=off)
MSTP(71)=0	Final state radiation (0=off)
MSTP(81)=0	n.a.
MSTP(91)=0	n.a.
MSTP(111)=0	Hadronization (0=off)
MDME(174,1)=1	Decay channel for gamma/Z: d quarks
MDME(175,1)=0	u quarks
MDME(176,1)=0	s quarks
MDME(177,1)=0	c quarks
MDME(178,1)=0	b quarks
MDME(179,1)=0	t quarks
MDME(182,1)=0	electron
MDME(183,1)=0	electron neutrino
MDME(184,1)=0	muon
MDME(185,1)=0	muon neutrino
MDME(186,1)=0	tau lepton
MDME(187,1)=0	tau neutrino
end	Tells pythia.f to stop reading Pythia parameters
1000,0,2,91.189D0	# events to generate / turns off printing of decay table / type of collider (0=ppbar,1=pp,2=ee) / collider energy
end	Tells pythia.f to stop reading input

Before using Pythia, an hbook file must be created where all of the above parameters are set.

Forms a process



•After manipulating the MSTP(43) parameter (composition of Z boson), I was able to simulate the collision of an electron and a positron which would result in the formation of either a Z boson (a massive neutral carrier particle of the weak force), a photon, (the carrier of the electromagnetic force), or a quantum mechanical state that is a result of the interference of the two possible wave functions.

Sample Log

Event listing (summary)

I	particle/jet	KS	KF	orig	p_x	p_y	p_z	E	m
1	!e+!	21	-11	0	0.000	0.000	45.594	45.594	0.00
2	!e-!	21	11	0	0.000	0.000	-45.594	45.594	0.00
3	!e+!	21	-11	1	0.000	0.000	45.594	45.594	0.00
4	!e-!	21	11	2	0.000	0.000	-45.594	45.594	0.00

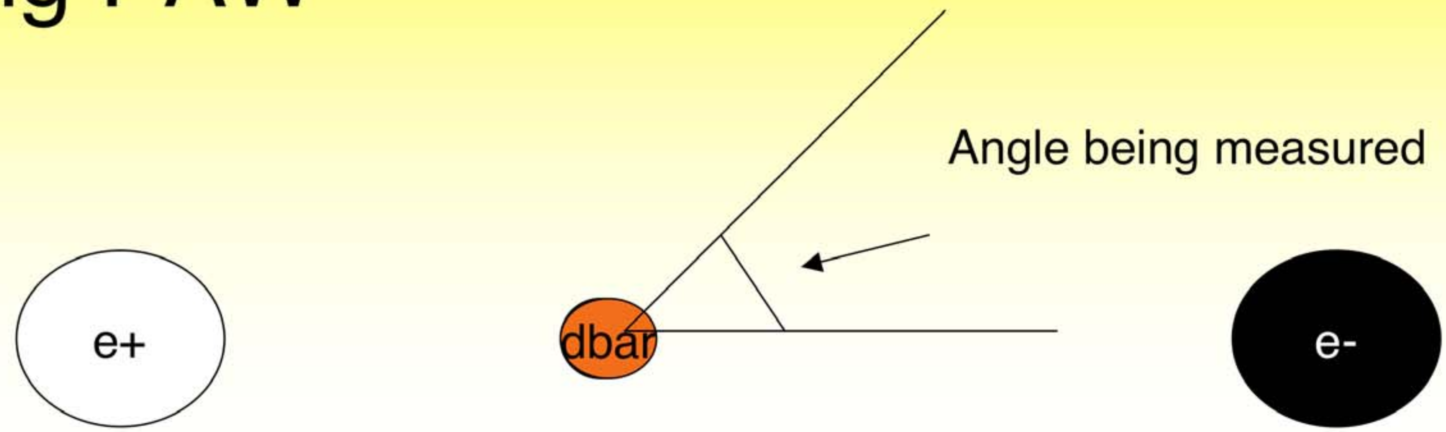
- A log file is created after running the file with the specified parameters through Pythia
- Each particle involved in each event is labeled for example: e- for an electron
- This label is followed by a number code which distinguishes each particle.
- The number code column is then followed by the origin which numbers each particle to show the physicist when the particle was created and decayed. The primary particles have 0 as their origin, the final particles are not surrounded by parentheses to signify that they do not decay.

The Monte Carlo Method

- After the log file is created, one can extract specific data and create histograms using the Physics Analysis Workstation (PAW).

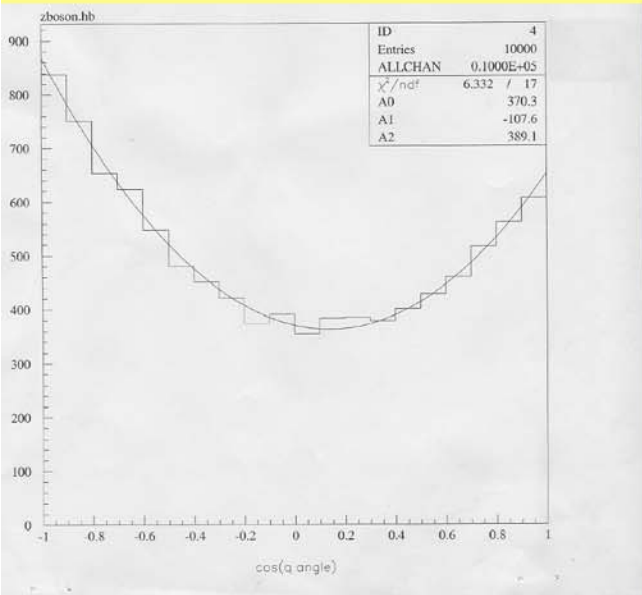
- After running several events, using Pythia, the average fit of all of these events will produce information which models real life, this is the idea behind the Monte Carlo Method.

Manipulating Data Using PAW

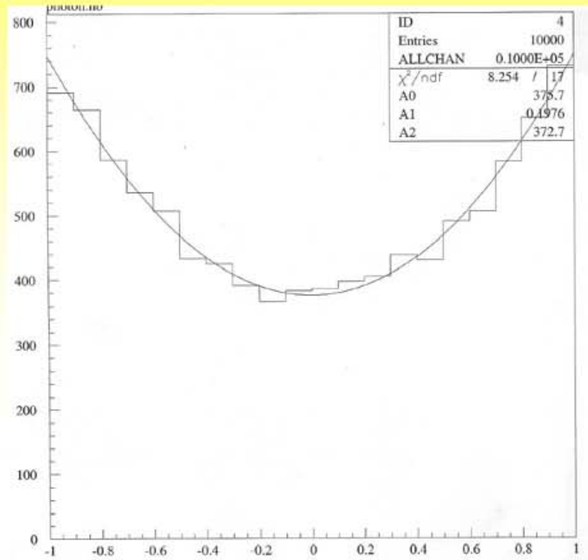


- Using PAW, I was able to look at the angle that the down quark made with respect to the original electron path in each event

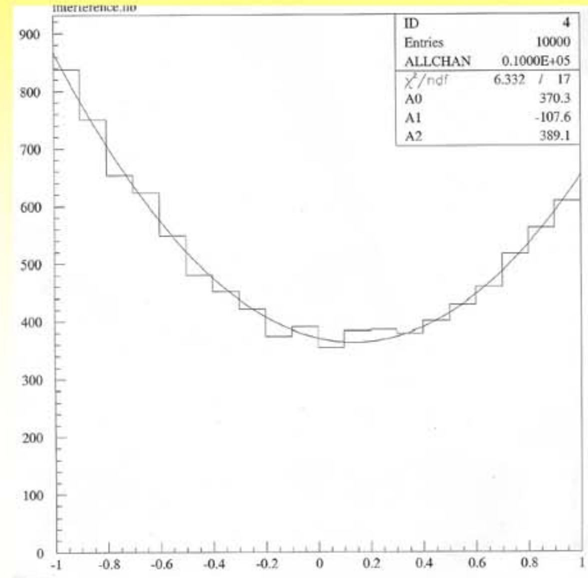
Histograms



Z boson



photon

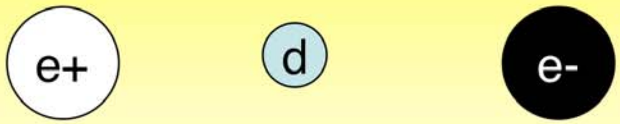


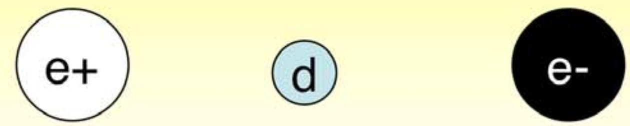
interference

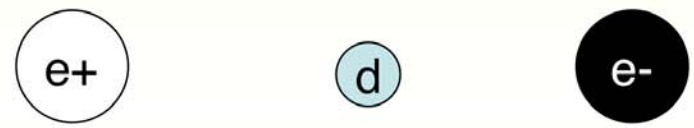
Histograms showing number of events vs. angular distribution

After the histogram is plotted, a fitted curve can be added to the histogram.

Interpreting the Histograms







When the electron-positron process formed a Z boson or the quantum mechanical interference state, in the majority of the events the down quark stayed in the same direction as the original electron.

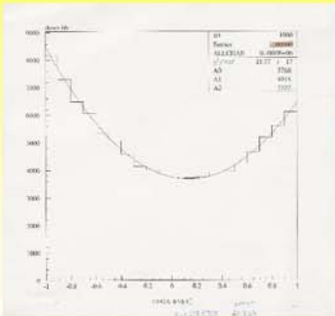
When the electron-positron process formed a photon, the amount of particles that continued on the original electron's path was equal to the amount of events where the quark recoiled.

Note: The antiparticles are not shown.

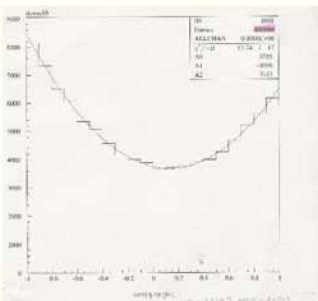
2nd Project

- Instead of altering the electron-positron process being formed, I forced the process to be a zboson and instead changed the flavor of the quark formed.
- I measured the cosine of the angle of the trajectory with respect to the original electron's path.

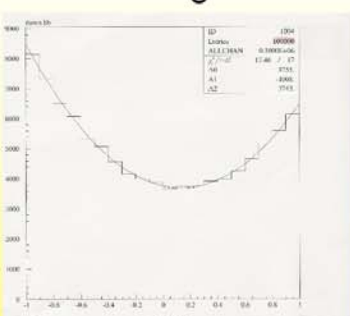
Histograms



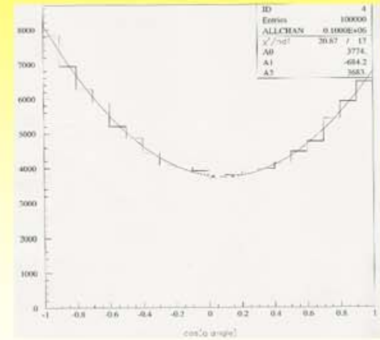
Bottom



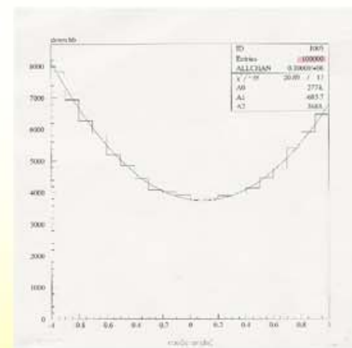
Strange



Down



Charm



Up

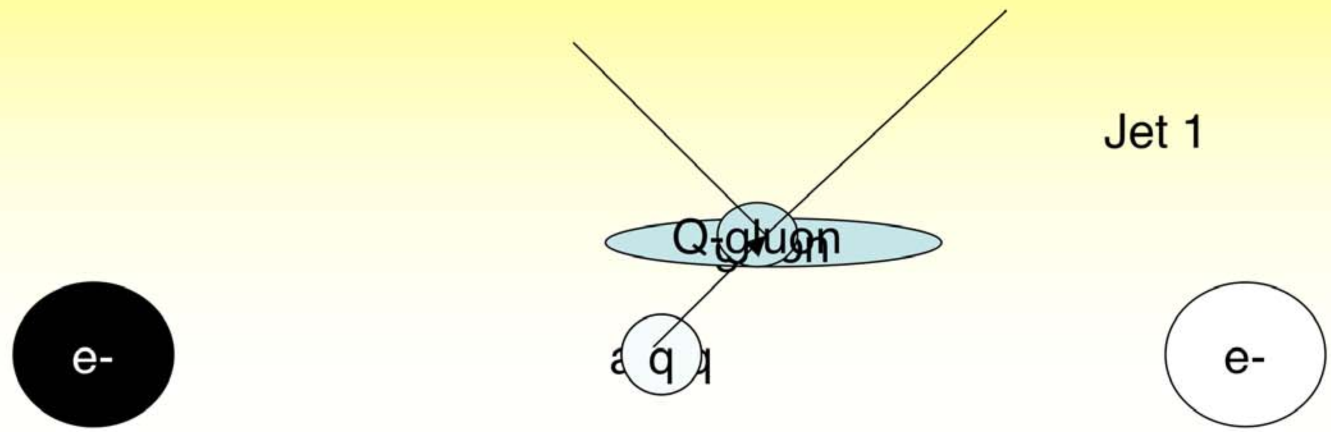
Analysis of 2nd Project

- After fitting curves to the quark histograms, I realized that the fits of the bottom, strange, and down quarks could be classified as one group while the histograms of the decays into up and charm quarks could be grouped into another.
- These differences in fits result from the different masses of the quarks.

Third Project

- Before this project, I looked at events where the quarks produced in the Z boson decay were observed directly, but this is not what happens in nature.
- In this project I was to take into account parton scattering or showering when observing the collisions of electrons and positrons.

Jets



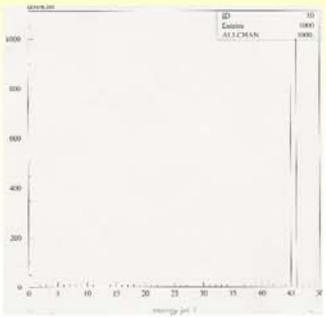
•The quark that is a product of the first decay releases gluons and in the process loses energy to the propagation of the gluon and the formation of this gluon from the mass of the original quark.

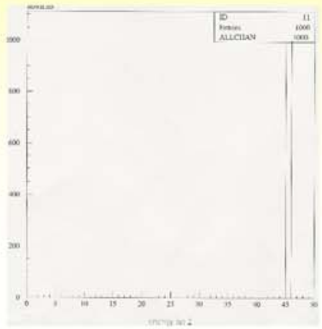
•Instead of a distinct quark that travels through space, after several jets the quark detected has a much lower energy than the original quark from the initial decay.

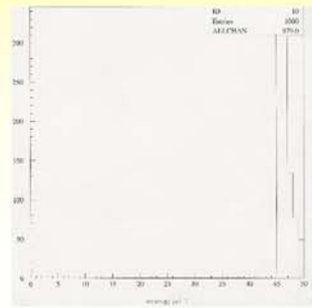
•Instead of turning the final state radiation parameter off, I turned on the MSTP(71) (final state radiation) parameter and thus allowed the third generation quark to shower, and thus form jets.

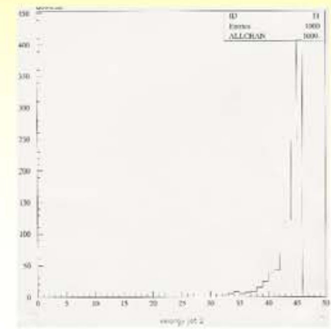
Analysis of the Third Project

In both cases there were only two jets because I did not alter the binding parameter PARU(44)









When final state radiation was not allowed both jets had the same energy.

- When final state radiation was allowed the jets were different.
- The most energetic jet could be greater than 45 GeV.
- The 2nd most energetic jet could be less than 45 GeV, but not higher.

Analysis of the Third Project

- After allowing final state radiation to occur, I compared the energy of the different jets to the cases when the radiation parameter was turned off.
- In both cases there were only two jets because I did not alter the binding parameter PARU(44),
- When final state radiation was not allowed both jets had the same energy.
- When final state radiation was allowed the jets were different.
    - The most energetic event could be greater than 45 GeV
    - The 2nd most energetic event could be less than 45 GeV, but not higher.
    - The Z boson decays into a down quark and its antiparticle
    - Example 1: If the down quark does not change color,
        - the energy of the jets is the same
        - the Z boson decays into a down quark and its antiparticle,
    - Example 2: The down quark changes color and exchanges a gluon which accounts for the lower energy of the 2nd jet.

Fourth Project

- I simulated the collision between a down hadron with its antiparticle. This collision resulted in the formation of a Z boson which quickly decayed into quarks and antiquarks. Using Pythia, I was able to restrict the flavor of these resulting quarks and antiquarks. Because quarks prefer colorless systems, they hadronize to form particles like rho mesons, pi mesons, while also releasing force carriers such as gluons and photons. With this setup, I measured the amounts of partons and gluons released some time and distance after the collision.

Results of the Fourth Project

- By changing the flavor of the quarks that resulted from the decay of the Z boson, the number and type of partons and particles released and/or formed changed.
- Upon observing the different types of partons created after the hadronization of the partons, one could see that a pi(0) meson usually decays into two photons.
- However, a more subtle occurrence was the equal numbers of pi(0), pi(+), and pi(-) mesons created. This is masked by the fact that the pi(0) has a shorter life than its other charged counterparts. It quickly decays into two photons.
- The equal amounts of each meson indicates the existence of isospin, an intrinsic property of quarks, which the strong force conserves during hadronization.

Conclusion

•Using Pythia, an event generator, and Monte Carlo Methods, the ideal collision of an electron and positron was simulated.

•After simulating the collision where a down quark and its antiquark were the result, the flavor of the resulting quark was altered.

•After allowing the Z boson to decay into all of the possible flavors, a parameter within Pythia was changed to account for parton scattering.

•After working with leptons, a collision between hadrons was simulated.

•This collision was clouded by the clustering of quarks via gluons in order to make colorless systems. This phenomenon is known as hadronization.